

## 9. Appendix : WFC3 Design Considerations

### 9.1 Overview

The design of WFC3 was driven by the need to provide high sensitivity over a broad wavelength region, excellent spatial resolution, and stable and accurate photometric performance. To cover the wavelength interval from 2000 Å to 1.7 μm, the WFC3 provides two science channels: the UVIS channel uses CCD detectors to support imaging between 2000 Å and 10500 Å, while the IR channel uses a HgCdTe detector array to image between 8000 Å and 1.7 μm. Both channels view the same on-axis field in the HST focal plane, but not simultaneously; a channel select mechanism is included to divert the light into the IR channel when this channel is used. An important driver in the design of WFC3 has been cost effectiveness. Hence, WFC3 will reuse hardware that flew on WF/PC as well as reuse designs from NICMOS, STIS, and ACS.

The UVIS channel is optimized for performance in the 2000 Å – 4000 Å wavelength interval, greatly enhancing HST's surveying capabilities at these wavelengths. The UVIS channel consists of an optical train providing focus and alignment adjustment and correction for the HST Optical Telescope Assembly (OTA) spherical aberration, a filter element selection mechanism, a shutter, and a CCD detector assembly. These are supported by a thermal control subsystem and also by control and data handling electronic subsystems. In general concept and functionality, as well as in many design details, this channel is patterned after the ACS/WFC channel.

The IR Channel consists of a selection mechanism to divert light from the UVIS channel, a separate optical train providing focus and alignment adjustment and correction for the spherical aberration, a filter element selection mechanism, and a HgCdTe detector assembly. These are supported by a thermal control subsystem and also by control and data handling electronic subsystems. This channel will be operated in a similar fashion to the NICMOS cameras.

### 9.2 UVIS Channel

#### 9.2.1 Field of View and Pixel Size

The field of view of WFC3 is limited to 160 x 160 arcsec by the size of the pick-off mirror (POM), which is constrained to avoid vignetting of other science instruments. Cost considerations lead the project to re-use the ACS/WFC camera-head design with 4096 x 4096 pixels in the focal plane. The pixel scale of 0.040 arcsec/pixel exploits the available field of view while providing good sampling of the Point Spread Function (hereafter PSF) in the visible. In order to increase the surface brightness sensitivity, the UVIS channel includes binned read-out modes (see 9.2.4).

## 9.2.2 CCD Detector

The UVIS channel has a focal plane populated by two 2048 by 4096 pixels CCDs butted together to yield a total of 4096 by 4096 pixels; the gap between the two chips will be about 15-20 pixels (0.6-0.8 arcsec) wide. The camera head is identical to that of the ACS/WFC channel.

The CCD detector sensitivity is optimized for the spectral interval 2000-4000 Å by adopting UV-optimized anti-reflection coatings on the CCDs and by using aluminum mirrors with magnesium fluoride (MgF<sub>2</sub>) coatings in the optical train. The aluminum mirrors required to have sensitivity below ~3500 Å reduce the throughput in the red part of the spectrum by (up to) 15 per cent per reflection. To achieve maximum sensitivity, the detector readout noise should be less than 4 electrons per pixel (with a goal of 2 electrons) and the dark current should be less than 10 electrons per pixel per hour. Such low readout noise and dark current permit background-limited observations in visible broad band filters.

Accurate photometric performance requires uniform response within each pixel and excellent charge transfer efficiency (CTE), which must be stable over a relatively long lifetime in the high-radiation environment where HST operates. The non-optimal CTE characteristics at launch and their further degradation on orbit have been an important limitation for highly accurate photometry with WFPC2. Preliminary tests suggest that this may be a problem for ACS as well. Knowledge about the problem and possible solutions have been incorporated into the high level requirements for the WFC3 CCD detectors. These include providing shielding to the CCD (equivalent to 1 cm of molybdenum as for ACS/WFC) and designing the CCDs with a mini-channel. In addition, an ACS-style post-flash capability will be included to reduce the effects of CTE loss in the later years by increasing the background level so as to fill the charge traps that are responsible for CTE loss.

Another important detector parameter is the modulation transfer function (MTF), which defines how photons impinging at a given location on the detector can generate detected signal in neighbouring locations. This phenomenon affects two areas: the uniformity of response within a pixel, which determines the potential photometric accuracy, and the cross-talk between pixels which degrades the PSF sharpness. Limits to the MTF were derived by requiring less than 10 per cent degradation in PSF width and better than 2 per cent photometry in the visible.

## 9.2.3 Spectral Elements

The UVIS channel makes use of the refurbished WF/PC Selectable Optical Filter Assembly (SOFA) unit which provides up to 48 filters. The UVIS filters provide broad, medium, and narrow bandpasses between 2000 and 10000 Å. The filter complement (Table 3) was recommended by the SOC with broad input from the astronomical community. It includes very broad band filters for the deepest possible imaging, filters which match the most commonly used filters on WFPC2 to provide continuity with previous observations, filters which are optimized to provide maximum sensitivity to various stellar parameters, and narrow band filters which probe a wide range of different physical conditions in the interstellar medium. A UV prism will also be available to support low resolution (R~200) slitless spectroscopy.

## 9.2.4 Operating Modes

When the whole array is read, each CCD in the UVIS channel is read out through two amplifiers. In addition to this standard read-out mode, sub-array and binned read-out mode are also supported. The sub-array mode allows the user to specify a sub-array of the desired size within a single CCD chip to be read through a single amplifier. Sub-arrays are used to minimize the read-out time and data volume for cases where repeated short exposures are required (e.g. solar system targets). Two binned read-out modes are supported, with  $2 \times 2$  and a  $3 \times 3$  binning. These allow for better surface brightness sensitivity for low background observations (e.g. for narrow band or UV observations) by reducing the relative contribution from read-out noise. Standard dithering patterns are included in the proposal software; these include patterns which allow for both integral and sub-pixel shifts (by moving the telescope.) These patterns help improving (recovering) the sampling of the PSF and minimizing the effects of detector defects.

## 9.3 IR Channel

### 9.3.1 Field of View and Pixel Size

The choice of the optimal pixel size for the IR channel resulted from a compromise between field of view and PSF quality. The latter is clearly very important when studying faint sources near bright sources, as for the cases of quasar host galaxies or crowded field photometry. These considerations led the project to consider in detail the properties of the PSF for the IR channel. The modeling is described in detail in the WFC3 Instrument Science Report 1999-01 “WFC3 Near-IR Channel: PSF and Plate Scale Study”. The conclusions of this study are that image reconstruction techniques are able to satisfactorily reconstruct a good quality PSF as long as the pixel size is below 0.15 arcsec. The final choice of 0.13 arcsec/pixel is dictated by optical packaging considerations. This pixel size yields a field of view of 135 by 135 arcsec.

### 9.3.2 IR Detector Array

The WFC3 IR detector is a 1024 by 1024 array of HgCdTe detectors on a silicon multiplexer. This array is a direct descendant of the NICMOS 256 by 256 and HAWAII 1024 by 1024 arrays in wide use in astronomy. To eliminate the complication and the limited lifetime of a stored cryogen system, the WFC3 IR detector is cooled with a six stage thermoelectric cooler. With this system, the nominal operating temperature is 150 K. The array sensitivity is optimized in the spectral interval 0.8-1.7  $\mu\text{m}$ . The lower wavelength cutoff is determined by the detector material, substrate and – to some extent – coating. In principle, HgCdTe detector arrays could have sensitivity well below 0.8  $\mu\text{m}$ . The upper wavelength cutoff can be varied by changing the composition of the detector material. A longer cutoff wavelength would increase both the dark current at a given temperature and the background due to thermal emission from the telescope and the optical bench. If compatible with technical constraints, the long wavelength cutoff will be pushed beyond 1.7  $\mu\text{m}$ . The detector read noise after multiple non-destructive read should not exceed 15.0 electrons per pixel (with a goal of 10 electrons per pixel). The sum of detector dark current and thermal background contributions should not exceed 0.4 electrons per pixel per second

(with a goal of 0.1 electrons/pixel/sec). These limits on read-out noise and dark current originate from the requirement of being able to carry out zodiacal background limited broad band imaging in the H band (1.6  $\mu\text{m}$ ).

To meet the image quality requirements set by the science program, the pixel cross talk should not broaden the PSF by more than 10 per cent and that photometric accuracy be better than 5 per cent.

### 9.3.3 Internal and OTA thermal background

Since the IR channel is not enclosed in a dewar, infrared thermal emission from the components in the optical bench creates an additional thermal load on the detector as well as generating a background which effectively increases the level of the dark current. This issue has been addressed by partly by cooling the optical bench and partly by designing a cooled, baffled camera head for the IR detector. This reduces the solid angle at the optical bench temperature seen by the detector, decreasing both the thermal load and the effective background. The filter wheel is also cooled to reduce the contribution to the background due to the potentially high off-band emissivity of the filters. Detailed modeling of the emissivity of the various components was carried out to optimize the design and is described in the document “WFC3 IR Channel In-Band Background”.

### 9.3.4 Spectral Elements

The IR channel filter wheel will have 18 available slots to be apportioned into 14 passband filters, two grisms, an open position, and a blank position (see Table 4). The filter complement recommended by the SOC, with broad community input, covers the extended range 0.6  $\mu\text{m}$  to 1.9  $\mu\text{m}$  and includes broad band filters, medium band filters centered on molecular lines and the nearby continuum, and narrow band filters probing interstellar diagnostic lines. The final selection of filters, in particular the choice between Paschen  $\beta$  and Paschen  $\alpha$ , will be determined by the detector cutoff wavelength of the flight array. The two grisms will provide WFC3 with the ability to take slitless spectra of sources at a resolving power of about 140 in the wavelength range 1.1  $\mu\text{m}$  to 1.7  $\mu\text{m}$  and of about 200 in the 0.9  $\mu\text{m}$  to 1.1  $\mu\text{m}$  range.

### 9.3.5 Operating Modes

The IR channel is read in MULTIACCUM mode, i.e. by performing up to 16 unevenly spaced, non-destructive reads during the integration. On orbit experience with NICMOS shows that this is a very effective read-out mode, able to both reduce the effective read-out noise and correct for most cosmic ray hits. Most IR observations are expected to make use of sub-pixel dithering to improve the PSF sampling. Such patterns are included in the proposal software. The IR channel also supports sub-arrays in order to allow for the short integration times required by bright targets (e.g. the HST standard stars and solar system planets).

Table 3: List of the filters in the WFC3 UVIS channel.

Fname	description	lambda (Å)	fw hm (Å)
F218W	ISM feature	2175	300
F225W		2250	500
F275W		2750	500
F336W	U, Stromgren u	3375	550
F390W	Washington C	3900	1000
F438W	W FPC 2 B	4320	695
F555W	W FPC 2 V	5410	1605
F606W	W FPC 2 W tile V	5956	2340
F814W	W FPC 2 W tile I	8353	2555
F475W	SD SS g	4750	1520
F625W	SD SS r	6250	1550
F775W	SD SS i	7760	1470
F850W	SD SS z	8320	>2000
F350LP	visible bng pass	3500	>7000
F300X	very broad U	2000	short
F475X	very broad B	3800	2200
F600LP	red bng pass	6000	>4000
F390M		3900	200
F410M	Stromgren v	4105	190
F467M	Stromgren b	4675	230
F547M	Stromgren y	5475	710
F621M	11% fil	6212	640
F689M	11% fil	6886	710
F763M	11% fil	7630	780
F845M	11% fil	8454	870
F280N	Mg II 2795/2802	2798	42
F343N	[Ne V] 3426	3426	228
F373N	[O III] 3726/29	3732	38
F395N	Ca III H&K	3950	61
F469N	He II 4686	4686	32
F487N	H-b 4861	4867	45
F502N	[O III] 5007	5013	47
F588N	He I 5876+Na I	5886	60
F631N	[O I] 6300+ [S III]	6306	54
F645N	Continuum	6455	82
F656N	H-a 6563	6563	14
F658N	[N II] 6583	6585	20
F665N	z (H-a + [N II])	6654	113
F673N	[S II] 6717, 31 & zHa+ [N II]	6731	77
F680N	z (H-a + [N II])	6902	288
F953N	[S III] 9532	9532	64

Fname	description	lambda (Å)	fw hm (Å)
Quads			
F191N	C III 1909	1909	30
F232N	C III 2326	2326	36
F243N	[Ne IV] 2425	2425	36
F378N	z ([O III] 3727)	3780	80
F387N	[Ne III] 3869	3869	26
F422M	continuum	4220	108
F437N	[O III] 4363	4364	30
F492N	z (H-b )	4924	78
F508N	z ([O III] 5007)	5081	112
F575N	[N II] 5755	5755	12
F672N	[S II] 6717	6716	14
F674N	[S II] 6731	6731	14
CH4A	25/km -agt	8890	89
CH4A	25/km -agt	9060	91
CH4A	0.25/km -agt	9240	92
CH4A	0.025/km -agt	9370	94
CH4B	CH4 6194	6194	62
CH4B	6194 left and right	6340	63
	[dual passband filter]	6038	60
CH4B	CH4 7270	7270	73
CH4B	7270 cont.	7504	75
P200	UV prism	2000	short
F657N	W tile H-a + [N III]	6573	94

Table 4: List of the filters in the WFC3 IR channel.

Fname	description	lambda (microns)	fwhm (microns)
F160W	Broad H and Red Grism Ref	1.6000	0.40000
F125W	Broad J	1.2500	0.30000
G141	"Red" Low Resolution Grism	NA	0.60000
F187N	Paschen Alpha	1.8781	0.01880
F184N	Paschen Alpha continuum	1.8350	0.01840
F127M	Water/CH <sub>4</sub> continuum	1.2700	0.07000
F139M	Water/CH <sub>4</sub> line	1.3850	0.07000
G102	"Blue" High Resolution Grating	NA	0.25000
F098M	"Blue" Filter, Blue Grism Ref	0.9850	0.17000
F164N	[Fe II]	1.6463	0.01646
F167N	[Fe II] continuum	1.6677	0.01668
F153M	H <sub>2</sub> 0 and NH <sub>3</sub>	1.5300	0.07000
F128N	Paschen Beta	1.2839	0.01284
F130N	Paschen Beta continuum	1.3006	0.01301
	<b>secondary selection</b>		
F126N	[Fe II]	1.2588	0.01259
F132N	Paschen Beta (redshifted)	1.3200	0.01320
F065W	Wide V (for UVIS redundancy)	0.6500	0.30000
F095W	Wide "z"	0.9500	0.30000
F140W	Wide Band spanning JH band	1.4000	0.40000

# **10. Appendix: List of WFC3 SOC and Science IPT Members, and IPT Organization Chart**

## **Scientific Oversight Committee**

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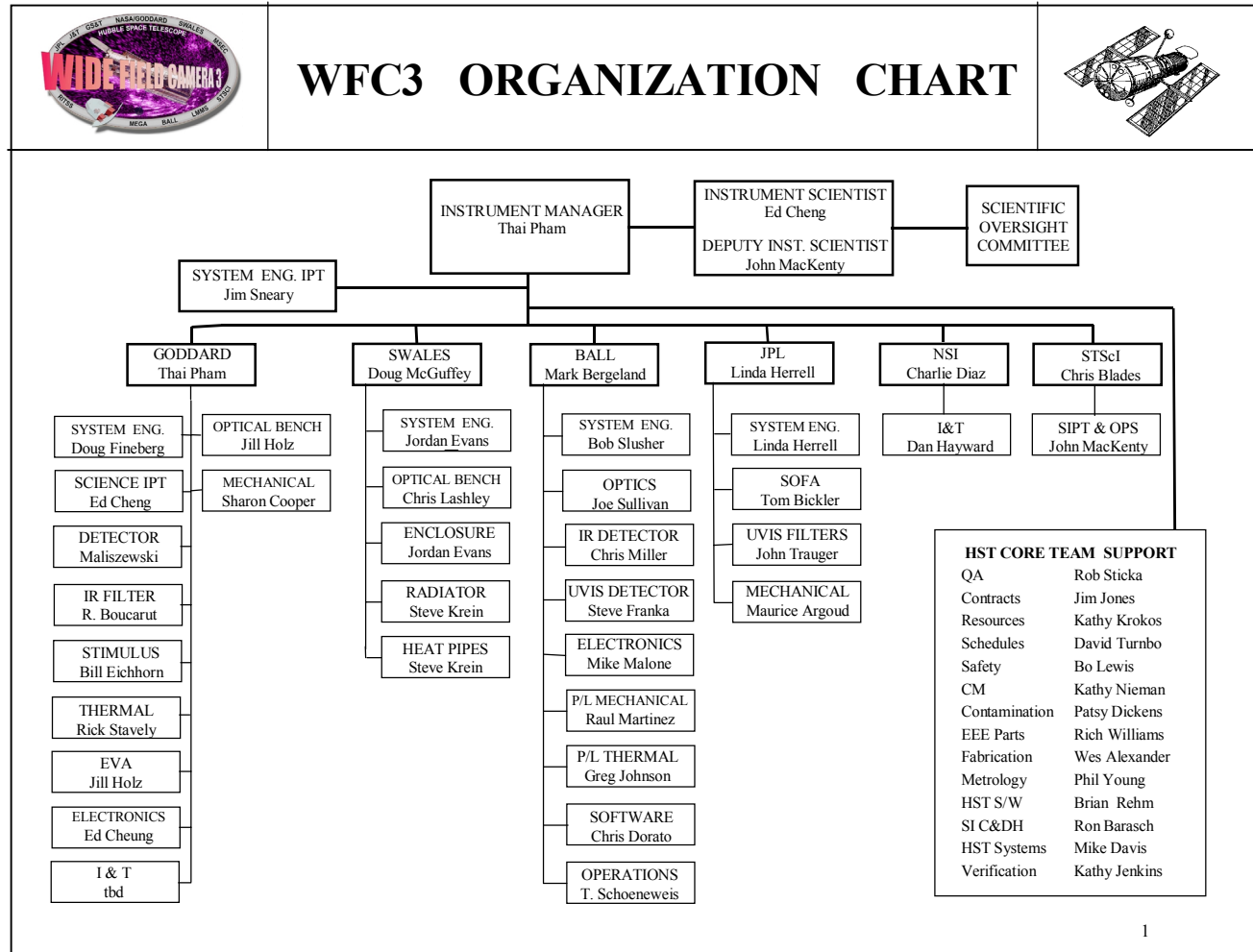
Olivia Lupie, STScI

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# Integrated Product Team Organization Chart



## 11. Appendix : Acronym List

ACS – Advanced Camera for Surveys

AO – Adaptive Optics

AGN – Active Galactic Nucleus

CCD – Charge Coupled Device

CTE – Charge Transfer Efficiency

FOV – Field of View

FUSE – Far Ultraviolet Spectroscopic Explorer

HRC – High-Resolution Channel (of the Advanced Camera for Surveys)

HST – Hubble Space Telescope

GALEX – Galaxy Evolution Explorer

HgCdTe – Mercury Cadmium Telluride (near IR detector array)

IDT – Investigation Definition Team

IPT – Integrated Product Team

IR – InfraRed , also channel of the Wide Field Camera 3

keV – one thousand electronvolts

MAMA – Multi-Anode Microchannel Array

MTF – Modulation Transfer Function

MgF2 – Magnesium Fluoride (mirror coating)

NCS – NICMOS Cooling System

NGST – Next Generation Space Telescope

NICMOS – Near-Infrared Camera and Multi-Object Spectrometer

OTA – Optical Telescope Assembly

PC – Planetary Camera (of the Wide Field and Planetary Camera 2)

POM – Pick-Off Mirror

PSF – Point Spread Function

QSO – Quasi Stellar Object

SBC – Solar Blind Channel (of the Advanced Camera for Surveys)

SDSS – Sloan Digital Sky Survey

SIM – Space Interferometry Mission

SIRTF – Space InfraRed Telescope Facility

SOC – Science Oversight Committee

SOFA – Selectable Optical Filter Assembly

SOFIA – Stratospheric Observatory for Infrared Astronomy

STIS – Space Telescope Imaging Spectrometer

STScI – Space Telescope Science Institute

TEC – thermo-electric cooler

UV – UltraViolet

UVIS – Ultraviolet and Visible (channel of the Wide Field Camera 3)

WF – Wide Field (of the Wide Field and Planetary Camera 2)

WFC – Wide Field Camera (of the Advanced Camera for Surveys)

WFC3 – Wide Field Camera 3

WF/PC – Wide Field and Planetary Camera

WFPC2 – Wide Field and Planetary Camera 2

2MASS – Two Micron All Sky Survey

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